

sclerite with hook arising at high angle. Dental, accessory, hypostomal and infrahypostomal sclerites prominent. Pharyngeal sclerite well formed and quite heavily pigmented. Dorsal and ventral cornua fenestrate. Cornua sometimes divergent posteriorly. Lower surface of ventral cornu almost concave in outline. Over-all length of skeleton 1.05 mm.

*Third stage larva.*—As in *cooleyi*. Length 8.00 to 18.00 mm, diameter 1.5 to 4.0 mm; at maturity (average of 10) 16.79 mm. Setulae of cuticle may be black at tip or colorless. Bands on anterior margins usually complete on segments 2 through 10; incomplete on segments 11 and 12. Bands on posterior margins usually absent on segments 2 through 4; incomplete on segments 5 through 7; complete on 8 through 11. Ratio of width of one spiracle to distance between spiracles 5.4 to 2.5. (Average of 10) One specimen, obviously atypical, was observed with three slits in the left spiracle and two in the right.

*Cephalopharyngeal skeleton* (Fig. 9).—Similar

to *cooleyi*. Mouth hook with small tooth on the underside at base. Dental sclerite robust. Parastomal sclerite slender and usually bent up at the tip. Pharyngeal sclerite quite heavily pigmented. Dorsal and ventral cornua fenestrate. Dorsal cornu comparatively more slender. Cornua divergent posteriorly. Lower edge of ventral cornu flattened or concave in profile. Over-all length of skeleton 1.43 mm.

*Pupa.*—As in *cooleyi*. Ridge connecting anal tubercles and posterior tubercles usually weakly developed or absent.

#### LITERATURE CITED

- GREENE, CHARLES T. *The puparia and larvae of sarcophagid flies.* Proc. U. S. Nat. Mus. 66(29): 1-26. 1925.
- KNIPLING, EDWARD F. *A comparative study of the first-instar larvae of the genus Sarcophaga (Calliphoridae: Diptera), with notes on the biology.* Journ. Parasit. 22(5): 417-454. 1936.
- ROOT, FRANCIS M. *Notes on larval characters in the genus Sarcophaga.* Journ. Parasit. 9(4): 227-229. 1923.

ENTOMOLOGY.—*Some work of the periodical cicada.* E. A. ANDREWS, Johns Hopkins University. (Communicated by Paul H. Oehser.)

The periodical or seventeen-year cicada, found only in North America, has a subterranean life years longer than that of numerous other cicadas and an aerial life of a few months. Joining these two major parts of its life history are two briefer links: a few weeks late in summer when the eggs left by females inside the wood of twigs develop into minute young nymphs, which enter the ground; and a few weeks in spring when the subterranean nymphs come near the surface and become ready to emerge and transform into adults or imagoes. Some of the work done by the surface dwellers as observed at Baltimore, Md., is here described.

#### THE LAST DWELLING

During their years under ground the young cicadas shed from time to time, grow rapidly, and make successive mud dwellings attached to roots from which the nymphs suck their nutriment, being parasites upon many trees. In Baltimore Potter (1839) observed the largest of these dwellings some 18 inches below the surface. Each was a rough ball of earth  $1\frac{1}{2}$  to 2 inches long and three-fourths of an inch wide, lined by smooth

mud, and contained one nymph. Emerging from such last feeding chambers the nymphs dig upward and construct somewhat different dwellings (Fig. 1). Within the mud tubes they rest some weeks till ready for emergence and transformation. These last dwellings have the advantage of safety some inches below the surface, along with quick access to the surface when the proper time comes. Each dwelling (Fig. 1) has rounded ends above and below as in previous subterranean dwellings, but these are connected by a long shaft and are commonly 150 to 350 mm long, though they may be longer or much shorter. In this shaft the lymph climbs up close to the surface or falls rapidly down to the bottom to escape attacks. In cross section the shaft is circular or sometimes elliptical, being wider than deep, and is about either 10 or 15 mm in diameter. Dwellings of these two sizes occur in the same places, but one or the other predominates, a fact that harmonizes with the occurrence here of a larger and a smaller variety of cicada of which one or the other is more abundant under certain trees. Also the larger bores were found where the larger cicadas emerged; that is, the bores were made to fit the cicadas.

The lining of the shaft is smooth mud a few millimeters thick, sharply defined from the lumen, but fading off gradually into the surrounding earth. Shafts are by no means always straight, or of uniform diameter, but may be sinuous and present swollen regions 20 mm wide. But I have not seen regular swellings near the upper end, as noted in another part of Maryland by Snodgrass (1921). Following his method we filled shafts under a purple beech tree with plaster of Paris and obtained such demonstrations of the abundance and character of these dwellings as shown in Fig. 2. The topsoil was such a mass of small stones and roots as to indicate that the nymph must have cut off small roots in order to advance so many inches. Large obstacles were often



FIG. 1.—Plaster cast of common or typical dwelling showing bottom chamber, long shaft, and dome above connected to surface by short exit passageway added by escaping larva. One-half natural size.



FIG. 2.—Plaster cast of nine dwellings in natural association, lengths, widths, and shapes, but with upper ends obscured in excess surface plaster. About half natural size. Photograph by Charles H. Weber.

avoided by change of direction, but at times small stones or roots projected into the lumen, covered with lining mud, and reduced the cavity from its normal 15 mm to a mere 10 mm in diameter. Staining of the plaster casts by topsoil or by clay showed that the lining material came from that level and was not brought up from below, which is in harmony with descriptions of the way in which cicada dwellings are made, namely, by forcing the earth laterally aside into its walls and not by carrying it away, as is done by many burrowing animals.

The chief implements used in making cavities in the earth, according to Marlatt (1907) and Snodgrass (1921), who observed the work in vessels of loose earth, are the big first legs (Fig. 3). Here, as in the other legs, the terminal segment is used chiefly in walking and may be folded down when not needed; the second segment from the tip is used to pick off particles of earth. The third segment is the largest and like a powerful thumb acts with the opposing second as a forceps to pick up pellets of earth and small stones. The minute particles picked loose from the earth are raked together by the tip segment to make a pellet, which the forceps can carry or shove into the walls of the cavity. However, all parts of the

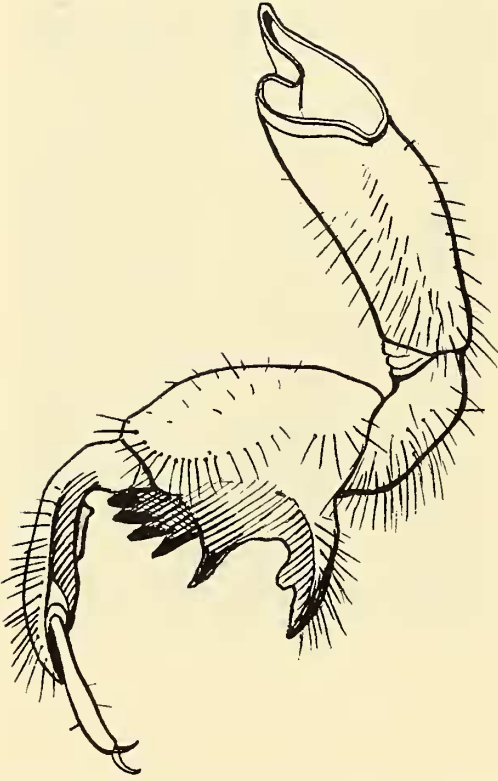


FIG. 3. Snodgrass's sketch of inner face of first right leg, or claw, of cicada pupa. The thickest segment is the femur, the next pointed segment the tibia, and the small final segment the tarsus.

body may come into use, for the hind legs and the abdomen may help shove earth aside and the head may carry earth plastered upon it. In vertical tunnels the animal braces its legs against the sides and, if disturbed, relaxes and drops down.

Finally completed, the last dwelling (Fig. 1) ends above and below in swellings similar to the ends of the preceding feeding dwellings. The lower cavity may be called the chamber and the upper one the dome. The lower chamber is large enough to allow the nymph to turn about and commonly is flattened below, as if to allow the nymph to rest upon a flat surface. Often the chamber slants upward to the shaft, as in Fig. 1, but sometimes the chamber is but the enlarged bottom of the vertical shaft and not turned to one side. The inner linings of both chamber and dome are of the same smoothness as in the shaft. Some measurements of these chambers were: Lengths, 24, 30, 60, 70 mm; widths and heights, 15 or 20 mm. The dome or top of such dwellings

comes remarkably near the surface of the earth without breaking through, leaving but a few millimeters of earth till the time for transformation, when the nymph digs its way out. The axis of the dome may be vertical, as in Fig. 4, or horizontal, as in Fig. 6. In the larger nymphs the claws may be stretched out 5 or 6 mm ahead of the animal, which so might receive sensory impressions of obstacles, or of the near surface, and then stop or turn aside; but when it turns aside horizontally, as in Fig. 6, when still 20 mm beneath the surface, it may be the warmth of the surface earth that influences the animal.

Examination of very many tubular dwellings, as well as their plaster casts, shows that, as with many small boring animals, closely neighboring cavities do not interconnect, but each has its own individual upper end and exit and along its course avoids contact with other dwellings though they often run close together. In such shafts as shown in Fig. 5 a common exit might have easily been made. While some unusual dwellings do run horizontally close to the surface, I saw none with the sharp U turn indicated in the picturesque illustration printed by Lander (1894). Yet there were some noteworthy abnormalities; thus in Fig. 7 the lower end of the dwelling is bifurcated; there is a normal chamber on the right and a supernumerary one on the left, as if two cicadas digging upward made two chambers that chanced to meet and were then continued as a single shaft.

A second bifurcation was found in granular red subsoil that had lain some years over topsoil. In this example the more normal chamber was 20 mm long and 15 mm wide and deep and inclined as usual, but the smaller extra chamber was

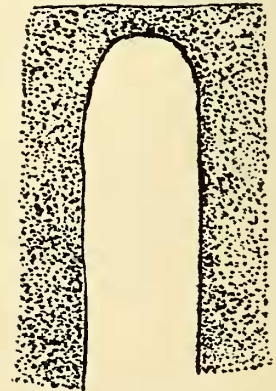


FIG. 4.—Upper end of shaft and dome coming up near to surface of soil. One-half natural size.



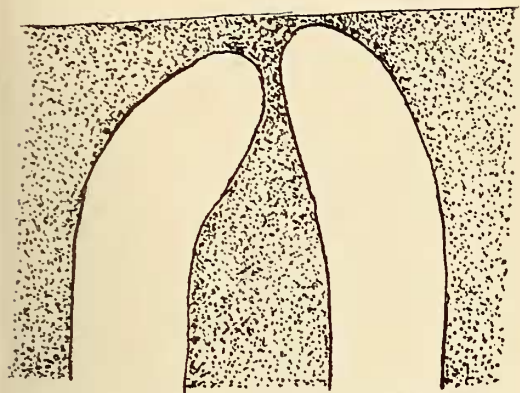


FIG. 5.—Two shafts ending in domes converging as if to have a common exist at surface. One-half natural size.

horizontal, at right angles to the shaft. Both chambers had flat bottoms roughened by particles fallen down the shaft before plaster was poured in.

#### IMPEDIMENTS TO THE MAKING OF DWELLINGS

In the red clay subsoil a cicada encountered a large slab of partly decayed wood, 30 mm thick, and continued its shaft through it and on up near to the surface. Also, under a privet hedge cicadas coming up under stiff flat dead leaves lying close on the surface continued their shafts through the leaves. Under a copper beech tree we placed obstacles on the surface of the ground: sheets of writing paper, brown paper, and carton pieces. When these lay long in contact with moist earth the cicadas, concealed below, destroyed their domes and dug round holes through the obstacles, even when many sheets were together, though when the obstacle was thick carton with heavy brown-paper surface and thick corrugated interior the cicadas merely bored diagonally in but not through. Having perforated the obstacle, the cicadas deposited pellets and some liquid mud

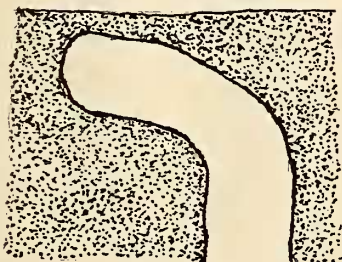


FIG. 6.—A 10-mm shaft turned nearly parallel to surface of earth. One-half natural size.

above the surface to form a new dome, as in the sectional view (Fig. 13). Stout paraffin paper lying under a pear tree was riddled with many round holes each surmounted with a thimble of mud.

We observed that under brick walks a few cicadas managed to find a way between bricks to the surface, and under large stones, logs, and

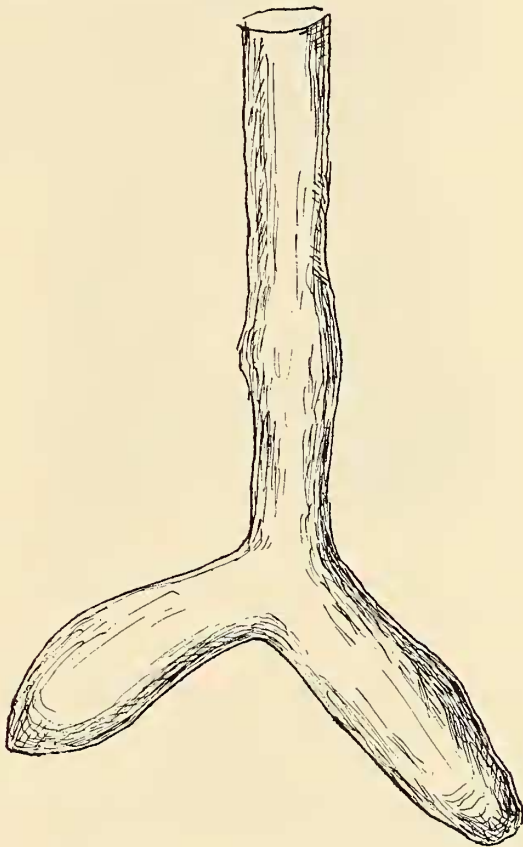


FIG. 7.—Plaster cast of abnormal dwelling with two chambers joined to a single shaft. One-half natural size.

planks many came up and then turned off horizontally. It may be many inches before they chance to come to an edge of the obstacle, when they then build upward again on the free surface as a new dome, standing forth into the air, but attached to the face of the obstacle. Under a thin sheet of metal covering about 1 square foot we saw many straight and curved shafts running in all directions, intermingled but each independent of others, some coming shortly to a free edge and others wandering far. Here there seemed no indi-



FIG. 8.—Photograph of four aerial structures (upper right of red clay) showing size, surface, form, and closed tops (except lower right, open on other side). One-half natural size. Photograph by Charles H. Weber.

cation that the cicadas found escape except by accident. But in some instances it seemed that the cicadas were guided by sunlight. Under a beehive, 40 by 50 cm, cicadas came up in six shafts, 11 to 85 cm deep, and, encountering the bottom of the hive built on horizontally extensions of the shafts, stuck to and suspended from the hive bottom like the work of termites or certain wasps. Though the hive contacted the earth about most of its edge, the west face was held up by bricks about 25 mm, so that light entered on that side. Three or four of the horizontal structures were aimed more to the west, the others had little length and seemed closed; while the longer ones had opened at the west end. The structure of these suspended mud tubes was that of the mud towers to be described later, with only a very thin mud lining against the roofing wood and the other walls, the mud being brought there and manipulated. A long row of beehives rested upon two parallel joists,  $3\frac{1}{2}$  by

$1\frac{1}{2}$  inches and 12 feet long, lying in contact with the earth and 10 inches apart and nearly east and west. When these joists were raised, many shafts were revealed, which turned off horizontally along under the joist. Under the northern joist, which was kept quite in the shade by the hives above it, 22 shafts ran from south to north and 19 from north to south, suggesting no guidance.

Under the southerly joist, which early in spring received sunshine before an overhanging apple tree was in leaf, the number going north was 14, south 68—a decided preference for the south direction. As no light entered between joist and earth, we infer the sunlight influenced the cicadas by warming the face of the joist toward which they were thus guided. Temperatures obtained on April 14, 1954, when the joist still lay in place were as follows: At noon along south side of joist in sunshine air read  $34^{\circ}\text{C}.$ , along north side, in shade of joist,  $28^{\circ}\text{C}.$  Thermometer bulb under south edge of joist read  $29^{\circ}\text{C}.$  and under north side  $28^{\circ}\text{C}.$  However, late in May, when air was  $21^{\circ}$  to  $24^{\circ}$ , the temperature under the joist was  $16^{\circ}$  to  $18^{\circ}$ , with no difference between north and south, as leaf shade kept the earth cool.

#### AERIAL DWELLINGS

Thus the last dwelling of the subterranean nymph is not necessarily restricted to the earth but may be continued up into the air. In fact, aerial extensions may be abundant and of great interest and are well known as turrets, towers, cones, chimneys, huts, and adobe houses. Perhaps the term "spigot holes" may refer to such aerial structures. If so, it is the earliest reference to

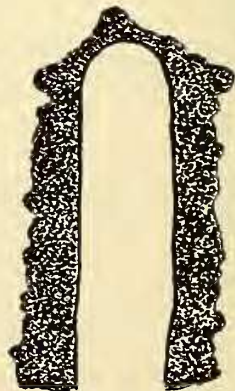


FIG. 9.—Vertical section of an aerial dwelling with shaft ending as a dome arched over with applied earth material. One-half natural size.



FIG. 10.—Photograph of three aerial structures; lower left, with dead leaves in walls and showing where one was pulled off a hole into lumen of shaft. Lower right, a lump as wide as tall closed as yet at top; upper, a sample of thimble called forth by presence of sheets of paper on surface of earth. One-half natural size.

them; it was used, as quoted by Marlatt (1907), by Thomas Mathews in 1705, writing of a swarm of cicadas in Virginia about the year 1675.

Probably the first illustration of such aerial dwellings was the above mentioned sketch by Lander (1894). Since then good photographs have been published. As shown in Fig. 8, made in Baltimore in 1953, these are large cylinders or cones of mud rough externally as made of pellets stuck together. The material may be topsoil or subsoil or mixtures of both, and some of it seems to have been flowing when applied. Some towers lean over but do not break even when nearly horizontal, which recalls the surmise made by Lander (1894) that the mud material was mingled with some cement supplied by the cicada. Several hundred pellets are seen in one tower, but others are concealed or fused together into larger lumps. These mud houses are durable. Some made late in April 1953 were still recognizable late in January 1954 where protected by dead leaves under privet hedges, despite rain, snow, frost, and thawing.

The walls (Fig. 9) are dense mud, not natural soil, externally more or less made of pellets but internally lined with the same smooth layer found in the underground parts of the dwelling. Rarely small sticks or leaves are incorporated in the walls, and stiff vertical dead leaves may form part of the lining, so that when torn away a hole is opened into the lumen, as in lower left of Fig. 10. When a tower was built up under layers of paper they were cut through and the tower com-

pleted above them, leaving the dome sticking up above the paper as in Fig. 11. As seen by comparing Figs. 9, 11, 12, and 13 with 4, the dome of aerial extensions is just like that of subterranean dwellings.

In size these aerial dwellings vary much in any locality, and some localities show an average different from that of some other locality. Thus 159 under separated box trees ranged in height from 15 to 90 mm, in width from 15 to 40 mm; with bores from 9 to 15 mm, thickness of roof of dome from 1 to 5 mm, exit hole from 6 to 15 mm. While under box trees grown as a hedge, 355 ranged in height from 30 to 100 mm, in width from 25 to 35 mm. Again under apple trees the range in height of 136 was from 15 to 100, in width from 10 to 40, with the bores from 7 by 9 to 15 mm.

#### FUSED AERIAL DWELLINGS

Often shafts are so close together that when extended into the air their walls stick together as one mass with from 2 to 10 separate domes. When but two (Fig. 14) they fuse all along one side only, though in exceptions (Figs. 15 and 16) a pair may lean together and fuse only above or may fuse below and diverge widely above. When several fuse a short dome may be overarched by a taller and so, apparently, the inmate cut off from escape except by digging through the taller neighboring dome. In fact, late in summer one such instance suggested that the inmate had died within unable to escape. However, several others



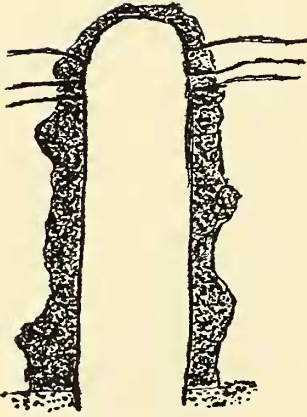


FIG. 11.—Vertical section of an aerial dwelling built up under three layers of paper through which it was continued to end as a dome. One-half natural size.

were found closed with no such cause for failure to escape.

Very rarely was there evidence that cicada nymphs ever made any use of their neighbors' work; in one instance three shafts had but two exits since one inmate had opened its shaft into that of a neighbor. Fig. 14 shows a certain economy of building material resulting from the crowding of neighbors, there being no room for the usual thick wall, only a thin party wall was built between neighbors. Such economy may lead to the observed fact that in some aggregates the entire weight is less than the combined weights of as many separate structures of similar heights.

#### ESTIMATES OF WORK DONE

Cicadas are muscular animals; even the slow nymphs underground move from place to place, build feeding chambers, suck sap and inject liquid to aid in feeding, and finally construct elongated dwellings that may extend up into the

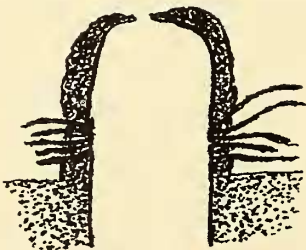


FIG. 12.—Five layers of paper over a concealed shaft were cut through to end as a dome, not yet quite finished late in summer. One-half natural size.

air. This enables one, by weighing the earth deposited, to estimate some of the energy expended in carrying earth upward several inches. Some of these deposits under apple, beech, and English box trees were collected and weighed, with ranges from 4 to 274 grams each. In all 1,116 of these came from under box trees, 149 in number, covering a sum of areas measured as about one-thirteenth of an acre. They weighed 16,578 grams, or about 28 pounds; i.e., at the rate of 364 pounds per acre. However, a correction is necessary since the dwellings were weighed after air drying all summer, but when originally carried up by the cicadas they were wet. When 20 dry dwellings were dipped in water and drained it was found they had taken up 25 to 35 per cent of their weight. Again 20 were ground to powder and weighed as water was added. When the mass was plastic enough to be made into pellets with the fingers, 39 per cent water had been taken up; with more water the mass lost form and began

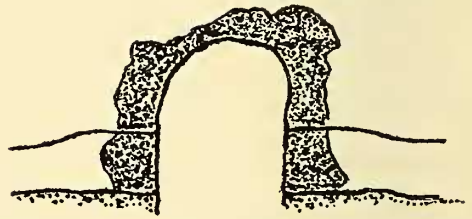


FIG. 13.—Two layers of paper over a concealed dome were cut through to form a dome above those obstacles. One-half natural size.

to flow when 43 per cent had been taken up. So we add at least one-third, or considering that some of the cicadas' material is liquid, as much as 40 per cent to the above dry weights, making thus, roughly, 500 pounds per acre, mined, brought up some inches, and deposited as dwelling walls.

#### PLACES AND CONDITIONS IN WHICH AERIAL HOUSES ARE MADE

In this arable soil aerial dwellings appear only in places that were shaded in April, under a building supported on brick pillars; under its eastern eaves shaded by evergreen privet; under the wooden steps of east and west ends of elevated wooden porch; but not under the porch itself where abundant in 1936 when adjacent bushes had not been removed; under English ivy covering the ground; under dense growth of dead nettle (*Lamium purpureum* L.), under north face

of privet hedge, and under its south face where dead leaves had collected; under evergreen cane and bamboo; under apple, beech, and English box trees. Also in the following peculiar conditions: under a board 16 inches wide and 19 feet long, supported at the ends 27 inches above the earth, surrounded by apple trees showing no aerial structures at all. In this faint shade, especially near its northerly edge, many fine dwellings were built up. When we moved this board 2 feet to the north, many soft new towers arose in the new shade.

The making of aerial dwellings by providing artificial shade was evoked as follows: Early in April a large zinc tub was overturned under one of the above apple trees known to have many subterranean dwellings under it and at length, April 29, a tower 2 inches in height arose under the

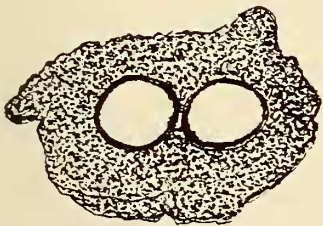


FIG. 14.—Cross section of two narrow shafts of aerial dwellings that coalesced with only a thin party-wall between. One-half natural size.

tub the night previous. This bent over nearly horizontally, and by May 3 the inmate had removed the old dome and added pellets making a new dome.<sup>1</sup> In a henyard, where there were only concealed dwellings, scraping the surface revealed 36 shafts thus opened, May 6; these were covered over with a large zinc tub making a dark space within which the next morning 30 soft dwellings had been built into the air, but outside the tub there were none. In the same region a number of chimneys arose from a square foot of hard earth when covered with a wooden trough. The previously described structures (p. 24), under joists, etc., are essentially aerial towers

<sup>1</sup> Whether in light or darkness each aerial dwelling is closed above, and if the old dome is removed a new one is made at once. Thus under dense lamium shade removal of domes was followed the next night by the making of new ones in most all the dark cavities formed by placing small tin cans, 4 by 2 inches, over the opened shafts. And under apple trees where the earth was very wet removal of 40 towers to reveal open shafts resulted the next morning, May 3, in the appearance of nearly as many new structures made within such cans and 3-inch flowerpots.

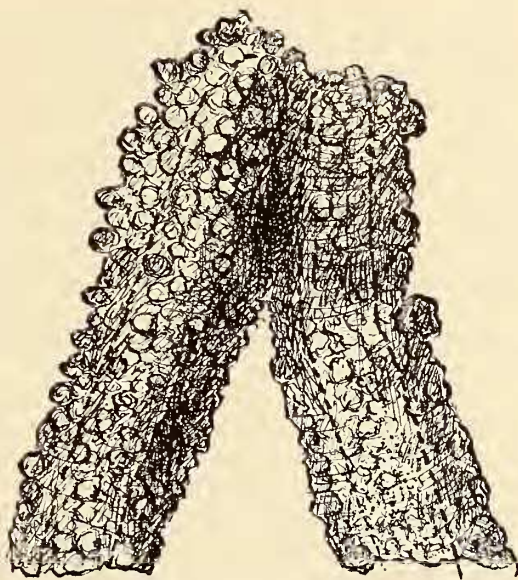


FIG. 15.—Two aerial dwellings leaning together and coalescing above. Both closed above. Lining indicated by broken lines. One-half natural size.

built in the dark and forced into horizontal postures.

#### HOW ARE AERIAL DWELLINGS MADE?

The aerial dwellings are built up rapidly in the night when no one has observed how, but we assume that they are made much as are the former feeding chambers, for knowledge of which we rely on the above-mentioned observations of Marlatt and Snodgrass. To this we add the following: In 1902 we saw cicadas, placed in tubes

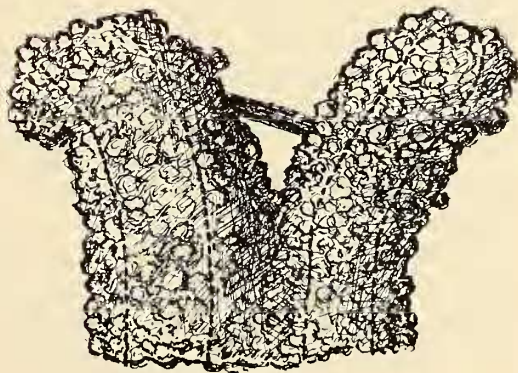


FIG. 16.—Aerial dwellings of a larger and a smaller variety built close together and then diverging widely. The large one on the left is open at top. A small stick was built into both where diverging. One-half natural size.



of loose earth, place mud onto the right and the left sides of the face and so carried it up to make pellets; also some huts found late in summer, 1953, with partly finished still-open domes suggest how domes are made in the air. Each (Fig. 12) had across its summit an open slit about 10 by 5 and 6 mm with very thin edges, not more than 0.5 mm. As yet no pellets had been placed over the top of the dome. We imagine the claws would reach out of the slit to apply mud, that the slender tarsus would be used in troweling the mud, and that water was supplied by the cicada nymph.

#### CONCLUSION

The last dwellings of seventeen-year cicadas are of interest as showing what insects can do with tools; as examples in the comparative architecture of dwellings of small animals; as a means for estimating some of the energy expended; and as beneficial factors in the life of these plant parasites. Also it is noteworthy that in the roofs of these last subterranean dwellings only a thin layer of earth remains to be perforated for egress into the air above; and that this advantage is persistently maintained under the diverse conditions we have described and illustrated.

When over 60 or more acres of woodland the earth is riddled with borings such as indicated in Fig. 2, the effects must be considerable, for these holes remain open for a year or more admitting air and surplus rain and serving for roots and for many insects, spiders, and other small forest creatures. Again, when towers of mud weighing perhaps 500 pounds per acre are deposited, ultimately to be disintegrated on the surface, thus "plowing" the earth after the manner of earthworms, there seems compensation for the injury done in sucking root sap and injury to twigs.

Why at some times and places the last dwellings are extended as aerial structures, huts, or towers is a question needing solution through experimentation.

It has been thought that these aerial dwellings were due to water, to peculiar soil, or to temperature. But in Baltimore the earth was no wetter where towers appeared than in nearby regions where subterranean dwellings sufficed—except only one place where surface water under an apple tree made a wet basis for towers, but here there was also shade in April, and this as well as

wetness may have acted by lowering the earth temperatures below that within the towers up in the warm air. Cicadas are parasites upon plants, drinking sap not only when young nymphs but when adults. That the oldest nymphs near the surface also drink sap is inferred but not demonstrated. That they are not necessarily restricted to sap for needed water is shown by the following experiment: Nymphs dug from their concealed shafts near the surface were kept some days in dry earth, each in a hole simulating a shaft, and then put onto garden earth. They at once thrust their beaks deep into the earth and, as if thirsty, stood long in the drinking attitude assumed by adults sucking sap from trees. Apparently they sucked moisture from the earth. Though they had been kept in darkness they had not erected aerial dwellings, nor had most of them even made domes over the holes they were in, presumably lacking sufficient water for such work. That liquid from the earth may be used by old nymphs for their building needs is implied in their long life near the surface when the earth is moist and there may be no roots to suck, as in the instance described above where they lived in granular red clay subsoil free from roots. It seems probable much of the liquid needed for mud making and even for self maintenance is derived from the earth.

With water constituting a third or more of the aerial dwellings, it is evident wet soil is needed for such work. As part of these aerial structures seems to be liquid mud and as we do not know how cicadas can carry liquid mud, we assume that they made the earth liquid when they used it. All through cicada life liquid is freely drunk and freely expelled, since, as described by Myers (1928), the cicada has a remarkable filtering apparatus that lets liquid pass rapidly out. Hence, whenever cicadas have liquid to drink they have it to expel.

When the actual process of hut-building is observed we anticipate it will be seen that the cicada uses both ends of its body, somewhat as we observed (1911) certain termites do when building in Jamaica.

Temperature has much to do with emergence, as shown when pipes heated the earth and cicadas emerged a year in advance. Hopkins (1898) observed in West Virginia that emergence was earlier where warmth was greater, either from lower altitude or from a more southern location.

Krumbach (1917) kept detailed records of temperatures in part of a botanical garden in Austria-Hungary, watched 27 cicadas emerge during 27 days, and also noted they emerged later in the shade of a wall. He was of the opinion that temperature was the important factor in bringing them forth. During the period of emergence temperatures were as follows: a meter above ground 11.2° to 19.2° minimum and 31.6° to 35° maximum; at the surface 10.8° to 16.2° minimum; down in the earth 300 mm 25.3° to 26.6°; down 600 mm 21.4° to 26.2°; down 1 meter 19.7° to 25.1°C.

Applying the above to our cicadas it may be that they were influenced by temperature gradients in coming up toward the surface and by surface temperature in emergence; also that a cicada in a tower might well be warmer than one beneath the surface. Lander (1894) studied cicadas near Nyack, N. Y., and concluded that the chimneys were built as places to cool off in, for he argued the very warm spring had unduly heated the trap rock, smoothed by glaciers, underlying the thin soil. But as no thermometer readings are given we are free to assume that the thin clay soil would not drain well into the glaciated rock but would hold the melted winter snow and be cold from evaporation, whereas cicadas up in towers would be warmed by the sunshine of an exceptionally warm spring.

That cicadas may get higher temperatures up in towers than down below is indicated by some experiments made in February and March 1954 at one of the spots in which chimneys had arisen in April 1953, which showed that a thermometer placed in a dry chimney over a hole resembling a cicada shaft registered 4° or 5° higher than down 1 to 7 inches in the earth, but only 1° lower than the warmer air. Thus on March 29, 1954, when the surface temperature of the earth was 28° in full sunshine, the temperature of the air was 19°, within the chimney 18°, at the surface 13°, down 12 inches 12°C.: in the shade of the same evergreen privet in which chimneys were made in 1953. This makes credible the view that in 1953 cicadas there found temperatures in their chimneys higher than below ground and comparable with that of the surface in full sunshine.

Moreover, as described above (p. 23), cicadas meeting certain obstacles continued their shafts horizontally as modified chimneys to the limit of the obstacle and then upward again to end with a

normal dome. Temperature taken there a year later showed that the sunshine warmed one face of the obstacle and that the cicadas, in the dark, in a majority of instances, built toward the higher temperature.

We advance the hypothesis that the chief factor in inducing the cicada to extend its last dwelling into the air is temperature; in the shade or under other conditions when the surface earth is not warm enough, a higher temperature is attained up in turrets surrounded with warm air.

Though most of the cicada's life with its growth and shedding is spent down in lower temperatures, we assume that higher temperatures are attained and probably needed for the final perfection of internal organs not needed in previous subterranean life. To test this hypothesis, temperatures might be obtained in air, on the surface, and beneath the ground over an area where cicadas are expected to issue soon. Such data might well indicate where aerial dwellings would arise and where only subterranean dwellings would be found.

#### LITERATURE CITED

- ANDREWS, E. A. *Observations on termites in Jamaica*. Journ. Animal Behavior **1**: 193-228. 1911.
- . *Periodical cicadas in Baltimore, Md.* Sci. Monthly **12**: 310-320. 1921.
- . *The seventeen year cicada, alias locust*. Quart. Rev. Biol. **12**: 271-293. 1937.
- HOPKINS, A. D. *The periodical cicada in West Virginia*. West Virginia Agr. Exp. Sta. Bull. 50: 46 pp., 23 figs., 1 map, 4 pls. 1898.
- KRUMBACH, T. *Zur Naturgeschichte der Singcicaden im Roten Istrien*. Zool. Anz. **48**: 241-250. 1917.
- LANDER, B. *Hut-building seventeen-year cicadas*. Sci. American **71**: 233-234. 1894.
- MARLATT, C. L. *The periodical cicada*. U. S. Dept. Agr., Bur. Entomology, Bull. 71: 181 pp. 1907.
- MATTHEWS, THOMAS. *Swarms of cicadas as one of the three prodigies appearing in Virginia about 1675*. (Quoted in "A Library of American Literature," ed. by E. C. Stedman and E. M. Hutchinson, vol. 1: 462-463. 1887.)
- MYERS, J. G. *The morphology of the Cicadidae (Homoptera)*. Proc. Zool. Soc. London, 1928: 365-472, 75 figs.
- POTTER, N. *Notes on the Locusta septentrionalis americanae decem septima*: 27 pp., 1 pl. Baltimore, 1839.
- SNODGRASS, R. E. *The seventeen-year locust*. Ann. Rep. Smithsonian Institution for 1919: 381-409, illus. 1921.